

Blazars, Gamma Ray Bursts and Galactic superluminal sources

GABRIELE GHISELLINI¹ AND ANNALISA CELOTTI²

¹*Osservatorio Astronomico di Brera, Via Bianchi 46, I-23807 Merate, Italy*

²*SISSA/ISAS, Via Beirut 2-4, I-34014 Trieste, Italy*

ABSTRACT. *BeppoSAX* is best known for its role in the disclosure of the Gamma-Ray Burst mystery, but it has also improved our understanding of jetted sources in general, and blazars in particular. On the interpretational side, we are curious to see if all sources with relativistic jets (or “flying pancakes”, as in GRBs) are controlled by the same basic physics, despite the very different lifetimes and behavior. To this end we explore some general characteristics of blazars, GRBs and superluminal galactic sources, such as their bulk Lorentz factors, the power of their jets compared with what they can extract through accretion, and the value of the magnetic field, close to the black hole, needed to extract the spin energy of a rotating black hole. We find remarkable similarities, namely that the outflowing mass rate is of the order of 1 per cent of the accretion mass rate in all systems, and that the value of the magnetic field required to efficiently extract the spin energy of the black hole is of the order of the gravitational energy density of the matter close to the gravitational radius. We then go on to discuss the way in which the energy in bulk relativistic motion can be transformed into beamed radiation, and consider the possibility that all three classes of sources could work in the same way, namely by a intermittent release of relativistic plasma at the base of the jet and thus with similar efficiency. Different patches of material, with slightly different velocities, collide at some distance from the black hole, producing the radiation we see.

1. Introduction

Radio-loud active galactic nuclei, galactic sources showing apparent superluminal motions (GS), and gamma-ray bursts (GRBs) are the three classes of sources where there is evidence for large quantity of matter moving very close to the speed of light. It is natural to wonder if these sources work in a similar way, namely if the machine able to produce, collimate and accelerate matter to relativistic velocities is the same. Furthermore one would like to know if in all three systems the radiation we see comes from the transformation of bulk kinetic (or magnetic) into random energy and, if so, if the mechanisms able to do that are similar. If this turns out to be true, then the galactic superluminal sources could be used as a sort of laboratory for the study of radio-loud AGNs, both because their vicinity (i.e. high fluxes) allows more detailed studies, but also because the ratio in black hole masses is probably 10^8 : if all timescales scale with the black hole mass, a millisecond in the life of GRS 1915+105 is equivalent to one day in the life of a blazars (see the recent review by Blandford 2002).

GRBs, on the other hand, are the most powerful events occurring after the Big Bang. But this *does not* mean that we are witnessing a single tremendous explosion. Indeed, GRBs have durations lasting up to hundreds of seconds, and recent modeling associates this time with the duration of the central engine powering them. Since a stellar mass black hole is involved, we have that a GRB of 100 s duration lasts for \sim a million of dynamical times. Put in this way, the “explosion” is instead a quasi steady-state process!

Thus the comparison among the three systems and their central engines is certainly legitimate, hopefully leading to a deeper understanding of how the formation, launch and acceleration of jet work.

2. The bulk Lorentz factor

Blazars — The best evidences for bulk relativistic motion in blazars come from VLBI observations of knots of radio emission moving superluminally. Apparent speeds up to $\beta_{\text{app}} = 30h^{-1}$ are measured (Jorstad et al. 2001, see also these proceedings), at least in those blazars that have been discovered by EGRET to be powerful γ -ray emitters. With $H_0 = 65 \text{ Mpc km}^{-1} \text{ s}^{-1}$, we have objects moving with $\beta_{\text{app}} \sim 40$, which indicates even larger Lorentz factors Γ (note that Γ must always be larger than β_{app}). These values are larger than the “fiducial” $\Gamma \sim 10$ we are used to, and can help solving the problem of the large radio brightness temperature of intraday variable sources (see Wagner & Witzel 1995 for a review), once corrected for interstellar scintillation (sources scintillate if their angular dimensions are small, hence the limit on the brightness temperature; Kedziora-Chudczer et al. 2001). Indications of a large degree of beaming come also from spectral fitting, especially of low powerful, TeV emitting, blazars where beaming factors $\delta > 20$ are derived (Tavecchio et al. 1998). There are also indications that the jet could be structured, with a fast “spine” surrounded by a slower “layer” (Laing 1993, Chiaberge et al. 2001), explaining for example why the non-thermal radiation of the core of radio-galaxies is not as faint as predicted if the plasma is moving at the same large speed and if they are observed at large angles with respect to the jet axis.

Galactic superluminals — Besides SS 433 ($\beta = 0.26$), GRS 1915+105 and GRO J1655-40 (both of them have $\beta \sim 0.9$ and $\Gamma \sim 2.5$) there are other recently discovered sources showing radio jets with moving features (see the reviews by Mirabel & Rodriguez 1999 and by Fender 2001). Among these, SAX J1819.3-2525 seems particularly interesting, since a new determination of its distance put this source at more than 8 kpc, much further away than previously thought (Orosz et al. 2001). If one assumes that the jets were ejected during one of the bright X-ray flares one then finds $\Gamma \sim 10$.

Gamma-Ray Bursts — We do not have direct measurement of Γ during the prompt emission, so we must rely on theory to estimate it: the “fiducial” value is $\Gamma \sim 100-300$. It cannot be much less than 100 to explain the very fast (millisecond) variability observed in the γ -ray light curve of their prompt emission. It cannot be much larger than that since otherwise we would have that the source (the fireball) becomes transparent to Thomson scattering before the acceleration phase ends, letting the internal radiation escape with a quasi black body spectrum (which is not observed, see Piran 1999 for a review). A similar constraint ($\Gamma > 100$) comes also from associating the emission above 100 MeV seen in a few cases with the prompt emission (see Fishman & Meegan 1995 for a review), thus imposing that the source must be transparent for the $\gamma\gamma \rightarrow e^+e^-$ process. Similarly to blazars, there is the possibility that also the “jets” of GRBs are structured, with the bulk Lorentz factor decreasing for increasing angles from the jet axis (Rossi, Lazzati & Rees, 2002).

3. The power of jets

Blazars — Without any doubt, the knowledge of the power and the energy carried by jets is the prime parameter to start any modeling. Despite this, the power of blazar (and radiogalaxy) jets is poorly known. This is due to two main reasons: 1) the radiation produced by relativistic jets is highly beamed, and the flux we receive is therefore highly enhanced (in blazars) or dimmed (in radiogalaxies) by relativistic effects; 2) we still do not know for sure the matter content of jets, i.e. we are still debating whether if most of the matter, is made by electron-positron pairs or by a normal electron-proton plasma. On the other hand, we know that the radio lobes of radio-galaxies and blazars are a sort of calorimeter, since the cooling time are long on these scales, and minimum energy considerations allow to estimate lower limits on the total energetics. Yet again, even in

this case we do not know either the contribution of protons to the total energy or the emitting plasma filling factor (see however recent results due to Chandra observations, Fabian et al. 2002). Bearing in mind these limitations, the total energy of a radio lobe, divided by its lifetime (estimated from spectral aging or from advance motion) allows to estimate the average power required by the radio lobes to emit and expand. This is the average power a jet must have. This estimate has been done, among others, by Rawling & Saunders (1991): they find an average power ranging from 10^{43} – 10^{44} erg s $^{-1}$ for FR I radiogalaxies to 10^{46} – 10^{47} erg s $^{-1}$ for FR II radiogalaxies and radio-loud quasars.

One can also calculate the power carried by the jet by inferring its density through modeling the observed SED and requiring that the jet carries at least the particles and the magnetic field necessary to make the radiation we see. This has been done on the pc scale by Celotti & Fabian (1993), on sub-pc scale (the γ -ray emitting zone) by Celotti & Ghisellini (2002, see also Ghisellini & Celotti 2002), and on the hundreds of kpc scale (the X-ray jets seen by Chandra) by Celotti, Ghisellini & Chiaberge (2001) and Tavecchio et al. (2000). These studies suggest large values of the power transported by the jet and require the presence of a dynamically dominating proton component (see also arguments by Sikora & Madejski 2000).

Galactic superluminals — The jet of Galactic superluminal sources is not a steady feature, and the conditions for the sporadic launching of jets in GRS 1915+105 and GRO J1655–40 are still under debate. But during the major flare events in GRS 1915+105 we can calculate the jet power by knowing the bulk Lorentz factor, the viewing angle, and assuming that the jet is at least carrying the particles and magnetic field that account for the synchrotron emission we see. Therefore, besides the bulk motion of the emitting particles, one has to account also for some of the jet power being in the form of a Poynting vector. We therefore have a powerful tool to find the *minimum* jet power, which corresponds to rough equipartition between the magnetic field and the particle density in the comoving frame. In this way Gliozzi, Bodo & Ghisellini (1999) estimated a *minimum* jet power in GRS 1915+105 ranging between 10^{39} erg s $^{-1}$ (pure electron-positron jet) and 10^{40} erg s $^{-1}$ (proton-electron jet).

Gamma-Ray Bursts — Are GRB collimated? If their emission were isotropic, then some of them would emit more than 10^{54} erg only in γ -rays. This is equivalent to one solar mass completely transformed into energy. One should not be particularly impressed by that, since the rotational extractable energy of black hole is 29 per cent of its mass, and therefore reaches 5×10^{54} erg for a $10 M_{\odot}$ black hole. On the other hand we do have some indications from afterglows that most of the emission is collimated in a cone of semiaperture θ_j , and that therefore the true radiated energy is a factor $(1 - \cos \theta_j)$ less than the isotropic equivalent (for two jets). The precise amount of collimation is uncertain (Frail et al. 2001, Ghisellini et al. 2002), and we do not know yet the value for the efficiency in transforming bulk energy into radiation. Most energy is however contained in the first prompt phase, and not in the much longer afterglow. Note that in the case of GRBs the word “jet” is somewhat misleading, since the radial extension of the “jet” is of order of hundreds of light seconds. This is the reason why Piran proposed the term “flying pancakes”. Bearing the above uncertainties in mind, the energetics of GRBs is in the range 10^{51} – 10^{53} ergs.

3.1. Comparison with accretion disk power

Blazars — The luminosity produced by the accretion disk in blazars L_d can be derived “directly” only when the blue bump is visible, i.e. when it is not completely swamped by the beamed non-thermal continuum or by the optical emission of the host galaxy. In many (but not all) cases we can however estimate it using the emission lines, both narrow (e.g. Rawlings & Saunders 1991) and broad (Celotti, Padovani & Ghisellini

1997). In completely featureless BL Lacs, instead, we can derive only upper limits for the luminosity of the disk. The most remarkable fact of these studies is that there is a rough equality between the average power of the jet and the power in the accretion disk, once an average covering factor of $\sim 10^{-2}$ and 10^{-1} is assumed for the narrow and broad line clouds, respectively.

Galactic superluminals — Here the disk luminosity is emitted at relatively soft X-ray energies, where photoelectric absorption can be an issue (possibly making SS 433 not so bright in X-rays). For GRS 1915+105 the X-ray luminosity, during flares, can be 10^{39} erg s $^{-1}$ (see e.g. Mirabel & Rodriguez 1999). The recent determination of the mass of its black hole (i.e. 14 ± 4 solar masses, Greiner 2001) makes the accretion disk of GRS 1915+105 Eddington limited. The ratio L_j/L_d of the jet power to accretion luminosity is then of the order of 1–10 during major ejection events.

Gamma-Ray Bursts — In GRBs the power due to accretion is completely unobservable. We must rely on theory and models to infer it. There is a growing consensus that long GBRs (i.e. GRBs whose prompt emission lasts for more than 2 seconds: these are the only ones for which the good locations allowed the follow-up observations in other bands) are associated with the collapse of stars more massive than ordinary supernovae (and therefore called hypernovae), or a two-step collapse forming first a neutron star and then a black hole (the SupraNova scenario of Vietri & Stella 1998). In any case the final resulting compact object is a fast spinning black hole surrounded by a very dense torus of mass $M_T \sim 0.1\text{--}0.2M_\odot$. It is possible that the duration of the GRB prompt emission is associated with the accretion time. If this is the case, the accretion rate is obviously huge even if the radiation that can escape is a tiny fraction, since the accreting material is completely opaque (scattering optical depths of order 10^{12} or so, see Table 1).

4. Outflowing vs accreting mass rates

For powerful blazars and Galactic Superluminals we can write:

$$L_d = \eta \dot{M}_{\text{in}} c^2 \quad (1)$$

$$L_j = \Gamma \dot{M}_{\text{out}} c^2 \quad (2)$$

and therefore

$$\text{Blazars, GS} \quad \frac{\dot{M}_{\text{out}}}{\dot{M}_{\text{in}}} = \frac{\eta}{\Gamma} \frac{L_j}{L_d} = 10^{-2} \frac{\eta_{-1}}{\Gamma_1} \frac{L_j}{L_d} \quad (3)$$

where η is the efficiency in converting the accreted mass into energy, \dot{M}_{in} and \dot{M}_{out} are the accretion and the mass outflowing rates, respectively. We use the notation $Q = 10^x Q_x$.

As mentioned, in GRBs we cannot estimate the mass accretion rate directly. Let us assume that the accretion process lasts for the duration of the burst, and that the total accreted matter corresponds to the mass of the torus surrounding the black hole, $M_T = 0.1M_{T,-1}M_\odot$. In this case

$$\dot{M}_{\text{in}} = 2 \times 10^{32} \frac{M_{T,-1}}{t_{\text{burst}}} \text{ g s}^{-1} \quad (4)$$

yielding

$$\text{GRB} \quad \frac{\dot{M}_{\text{out}}}{\dot{M}_{\text{in}}} = \frac{L_j t_{\text{burst}}}{\Gamma M_T c^2} = 5 \times 10^{-3} \frac{E_{\text{burst},52}}{\Gamma_2 M_{T,-1}}. \quad (5)$$

We then obtain the remarkable result that (at least in this model) the ratio of outflowing and accreting mass is roughly the same in blazars, Galactic Superluminals and Gamma

Ray bursts. *If true, this result could explain why GRBs fireballs have that particular barion loading*, which allows them to be at the same time light enough to be relativistic (contrary to supernovae), but heavy enough to convert all internal energy into bulk motion (requiring the fireball not to become transparent too early for scattering). Alternatively, one can *assume* that there is a typical (and fixed) barion loading in jets, thus deriving the resulting bulk Lorentz factor.

5. The central engine

There is some consensus (although certainly not unanimous) that the powering mechanism of jets is the extraction of rotational energy of a spinning black hole, through the Blandford & Znajek (1977) process. As an order of magnitude estimate, the power which can be extracted by this mechanism is (Blandford & Znajek 1977; Rees et al. 1982)

$$\begin{aligned}
 \text{Blazars} \quad L_{BZ} &\sim 6 \times 10^{46} \left(\frac{a}{m}\right)^2 M_9^2 B_4^2 \text{ erg s}^{-1} \\
 \text{GRBs} \quad L_{BZ} &\sim 6 \times 10^{50} \left(\frac{a}{m}\right)^2 M_1^2 B_{14}^2 \text{ erg s}^{-1} \\
 \text{GS} \quad L_{BZ} &\sim 6 \times 10^{38} \left(\frac{a}{m}\right)^2 M_1^2 B_8^2 \text{ erg s}^{-1}
 \end{aligned} \tag{6}$$

where (a/m) is the specific black hole angular momentum (~ 1 for maximally rotating black holes).

In the following we will compare the B -values required for the Blandford & Znajek mechanism to work with the gravitational energy density of the matter at R_s . To do that, we will assume that the accretion process, in blazars and in Galactic Superluminals, is converting in radiation a fraction $\eta = 0.1\eta_{-1}$ of the total accreted mass-energy: $L_d = \eta \dot{M}_{\text{in}} c^2$. This allows to estimate \dot{M}_{in} from the blue bump luminosity, or, when this is not visible, through the luminosity of the emission lines, (assuming they reprocess a fraction of L_d of the same order of the covering factor of the emission line clouds, i.e. 10% for the broad and 1% for the narrow emission lines, respectively).

For GRBs, instead, the mass accretion rate can be derived assuming, as a working hypothesis, that their duration is controlled by the time needed to accrete the mass of the dense torus surrounding the spinning black hole. In this way $\dot{M}_{\text{in}} \sim M_T/t_{\text{burst}}$.

To find the corresponding density n_p of the matter we use

$$\dot{M}_{\text{in}} = 2\pi R h \beta_r n_p m_p c \tag{7}$$

where $\beta_r c$ is the radial inflow velocity, and h is the height of the disk at the radius R . The gravitational energy density \mathcal{E} , close to the Schwarzschild radius is

$$\mathcal{E} \sim n_p m_p c^2 = \frac{\dot{M}_{\text{in}} c}{2\pi (R h / R_s^2) R_s^2 \beta_r} \tag{8}$$

Equipartition of the magnetic energy density [$B_{\text{eq}} = (8\pi\mathcal{E})^{1/2}$] gives

$$\begin{aligned}
 \text{Blazars, GS} \quad B_{\text{eq}} &= \left[\frac{4L_d}{\eta c (R h / R_s^2) R_s^2 \beta_r} \right]^{1/2} \\
 \text{GRBs} \quad B_{\text{eq}} &= \left[\frac{4M_T c}{t_{\text{burst}} (R h / R_s^2) R_s^2 \beta_r} \right]^{1/2}
 \end{aligned} \tag{9}$$

the fiducial values of B_{eq} are listed in Table 1 for the three classes of sources. One can see that the derived values are of the order required by the Blandford–Znajek process to provide the right power.

This can be taken as promising, since the found values match the required ones: note that it requires that the magnetic field energy density is of order of the gravitational energy density, which, depending on the accretion conditions, can be much larger than either the gas pressure of the accreting matter or the radiation energy density produced by accretion. This latter possibility appears to occur for GRBs.

In Table 1 we also list the value of the scattering optical depth, calculated in the vertical direction:

$$\tau_{\Gamma} \equiv \sigma_{\text{T}} n_{\text{p}} h. \quad (10)$$

We can see that in blazars it is of order unity, a few in (flaring) Galactic superluminals and huge in GRBs.

TABLE I
Fiducial Quantities. We use the notation $Q = 10^x Q_x$.

Parameter	Blazars	Gal. Sup.	GRBs	Units
Γ	10–30	2.5–10?	> 100	
Mass	10^8 – 10^9	~ 10	~ 10	M_{\odot}
$E_{\text{rot,max}}$	$5 \times 10^{62} M_9$	$5 \times 10^{54} M_1$	$5 \times 10^{54} M_1$	erg
L_{j}	10^{43} – 10^{48}	10^{38} – 10^{40} (flare)	10^{50} – 10^{52} (iso)	erg s $^{-1}$
L_{d}	10^{42} – 10^{47}	10^{38} – 10^{39}	?	erg s $^{-1}$
$t_{\text{life}} = E/L_{\text{j}}$	$5 \times 10^{15} M_9 L_{\text{j},47}^{-1}$	$5 \times 10^{15} M_1 L_{\text{j},39}^{-1}$	$500 M_1 L_{\text{j},52}^{-1}$	s
$t_{\text{life}}/(R_{\text{s}}/c)$	$5 \times 10^{11} L_{\text{j},47}^{-1}$	$5 \times 10^{19} L_{\text{j},39}^{-1}$	$5 \times 10^6 L_{\text{j},52}^{-1}$	
$n_{\text{p}} (@R_{\text{s}})$	$4 \times 10^9 \frac{L_{\text{d},46}(R_{\text{s}}/h)}{\eta_{-1} M_9 \beta_{\text{r}}}$	$4 \times 10^{18} \frac{L_{\text{d},39}(R_{\text{s}}/h)}{\eta_{-1} M_1 \beta_{\text{r}}}$	$7 \times 10^{29} \frac{M_{\text{T},-1}(R_{\text{s}}/h)}{t_2 M_1^2 \beta_{\text{r}}}$	cm $^{-3}$
$\tau_{\text{T}} (@R_{\text{s}})$	$0.8 \frac{L_{\text{d},46}}{\eta_{-1} M_9 \beta_{\text{r}}}$	$8 \frac{L_{\text{d},39}}{\eta_{-1} M_1 \beta_{\text{r}}}$	$10^{12} \frac{M_{\text{T},-1}}{M_1 \beta_{\text{r}} t_2}$	
$B_{\text{eq}} (@R_{\text{s}})$	$10^4 \left(\frac{L_{\text{d},46} R_{\text{s}}/h}{(\eta_{-1} M_9 \beta_{\text{r}})} \right)^{1/2}$	$4 \times 10^8 \left(\frac{L_{\text{d},39} R_{\text{s}}/h}{\eta_{-1} M_1 \beta_{\text{r}}} \right)^{1/2}$	$2 \times 10^{14} \left(\frac{M_{\text{T},-1} R_{\text{s}}/h}{t_2 M_1^2 \beta_{\text{r}}} \right)^{1/2}$	G

6. Internal shocks

In 1978, Rees proposed that the jet of M87 could be powered by collisions among different part of the jet itself, moving at different speeds. When colliding, they would produce shocks, giving rise to the non-thermal radiation we see. Although born in the AGN field, this idea of *internal shocks* grew up more robustly in the GRB field, to become the “paradigm” to explain their prompt emission (see e.g. Rees & Mészáros 1994).

Faster and later shells can then catch up slower earlier ones, dissipating part of their bulk kinetic energy into radiation. However, all shells are and remain relativistic: after the collision the merged shells move with a bulk Lorentz factor which is intermediate between the two initial ones. It is then clear that this mechanism has a limited efficiency, because only a small fraction of the bulk energy can be converted into radiation (unless the contrast between the two initial Lorentz factor is huge, see Beloborodov 2000, but also Ghisellini 2002).

In blazars, on the other hand, we *require* a small efficiency, since most of the bulk energy has to go undissipated to the outer radio-lobes. This model is very promising, since it can explain some basic properties of blazars:

- About 10 per cent of the power in bulk motion is dissipated into radiation, while 90 per cent is available to power the radio lobes.
- Most of the dissipation occurs at a few hundreds of Schwarzschild radii, far enough from the black hole and accretion disk to avoid relevant $\gamma\text{-}\gamma \rightarrow e^\pm$ absorption of γ -rays, but still within (in powerful objects) the broad line region, which provides seed photons for the Compton scattering process (leading to a dominant high energy emission).
- The shells that have already collided once can collide again, at larger distances from the black hole with reduced efficiency, since the Γ -contrast of the colliding shells decreases. This can explain why the luminosity of jets decreases (but it does not vanish) with distance. Fig. 1 shows the efficiency (i.e. the fraction of the luminosity emitted to the jet carried power) as a function of distance for a simulation we have done for Mkn 421 (Guetta et al. 2002).
- Variability is a built-in feature of the model. See Zhang et al. (2002, see also this volume), for an example of blazar variability that might be explained by internal shocks.
- There is the possibility (not yet studied in detail) of a link between the flares at optical and γ -ray energies and the flares in the radio-mm band (see Spada et al. 2001 for an example of correlation between the mm and the optical- γ -ray fluxes in 3C 279).

A detail study via numerical simulations of the predictions of this model in blazars has been carried out by Spada et al. (2001) for powerful objects (like 3C 279). We are now studying less powerful objects (like Mkn 421 and BL Lac itself, Guetta et al. 2002). As discussed by Kaiser, Sunyaev & Spruit (2000), internal shocks could also work for Galactic Superluminals, although detailed simulations have yet to be done.

6.1. Internal shocks and the blazar sequence

One of the important characteristics of the internal shock model for blazars is that the injection of energy in each collision is finite in time. The generation of relativistic particles lasts for the collision time, which is of the order of the time needed for one shell to overtake the other, i.e. $t'_{\text{inj}} \sim \Delta R'/c$ in the comoving frame. The energy distribution of the relativistic particles responsible for the emission, in this case, never reaches a steady state, and the maximum emitted flux corresponds to the end of the injection (if the energy distribution of particles, $N(\gamma)$, is steeper than $N(\gamma) \propto \gamma^{-2}$). *This can explain why there is a sequence in the SED of blazars:* in low power sources lacking emission lines the cooling time is long, and only the most energetic particles can cool in t_{inj} . Suppose to inject a power law of relativistic particles, between γ_{min} and γ_{max} , with slope s [i.e. $Q(\gamma) \propto \gamma^{-s}$]. After the injection phase (i.e. after t_{inj}), only those particles for which

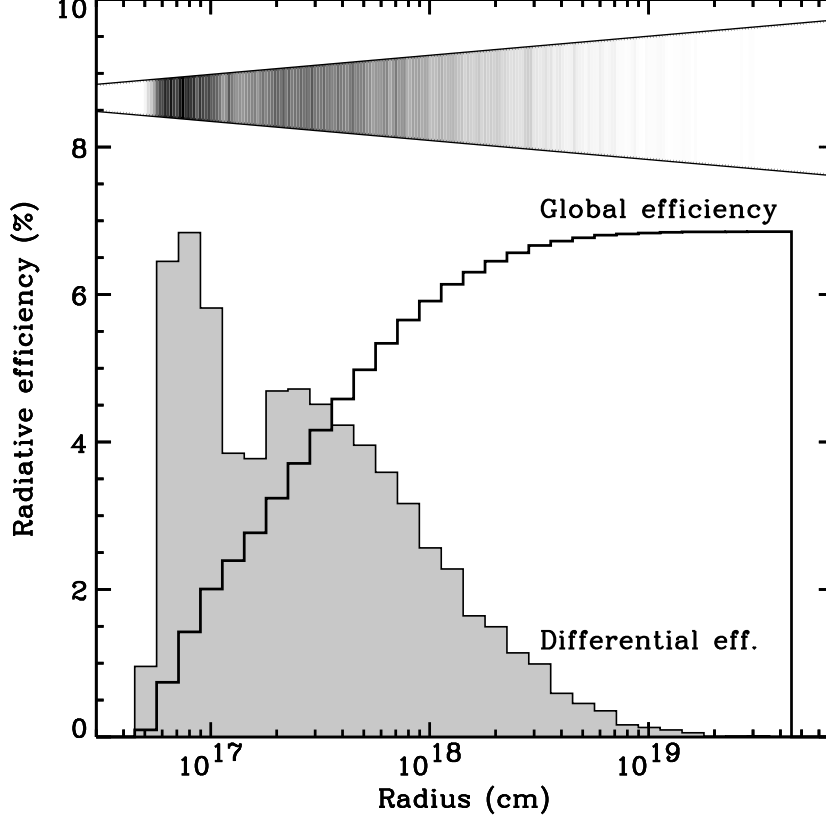


Fig. 1. The result of a simulation of the internal shock model for Mkn 421. We plot the average local radiative efficiency and the cumulative efficiency as functions of distance from the black hole. The first “peak” in the efficiency corresponds to the first collisions between shells, while the “tail” at larger distances corresponds to second, third (and so on) collisions. The minimum distance at which collision occur is dictated by the initial separation of the shells R_0 and their average bulk Lorentz factor Γ . For the first collisions we have $R_{\text{coll}} \sim \Gamma^2 R_0$. The top of the plot shows a schematic representation of the jet, with grey levels proportional to the local efficiency. From Guetta et al. (2002).

$t_{\text{cool}}(\gamma) < t_{\text{inj}}$ have cooled, producing a break in the particle distribution at $\gamma_c > \gamma_{\text{min}}$. Below γ_c the particle distribution retains its original slope [$N(\gamma) \propto \gamma^{-s}$], while above γ_c the distribution has a slope steeper by one $N(\gamma) \propto \gamma^{-(s+1)}$. If $2 < s < 3$ the peaks of the synchrotron and the inverse Compton spectra are produced by electrons at γ_c . For powerful sources, on the other hand, electrons of almost all energies can cool in a time t_{inj} , due to the larger magnetic field in their jet, but especially due to the contribution of the broad line photons which enhances the inverse Compton cooling rate. In this case the particle distribution $N(\gamma) \propto \gamma^{-(s+1)}$ above γ_{min} and $N(\gamma) \propto \gamma^{-2}$ below.

Therefore sources will have different peak locations, according to the amount of cooling suffered during the time of the shell-shell collision. Calling γ_{peak} the random Lorentz factor of those electrons emitting most of the radiation (i.e. emitting at the peaks of the SED), we find a correlation between γ_{peak} and the amount of radiative plus magnetic

energy density U (as measured in the comoving frame) which has *two* branches: in powerful objects $\gamma_{\text{peak}} = \gamma_{\text{min}} \propto U^{-0.5}$, while in weak lineless BL Lacs we have $\gamma_{\text{peak}} = \gamma_c \propto U^{-1}$ (Ghisellini, Celotti & Costamante, 2002).

7. Conclusions

We have rather compelling indications that relativistic jets in different systems are produced via similar processes, and that also the way in which they dissipate part of their kinetic energy into radiation may be similar. The matter outflowing in relativistic jets may be of the order of 1 per cent of the matter inflowing into the black hole. If powered by spinning black holes, the value of the magnetic field close to the horizon must be of the order of the gravitational energy density of the accreting matter, which can be much more of the gas or radiation pressure.

There is now growing consensus that the massive black hole in radio-loud AGNs exceeds $\sim 10^8 M_\odot$ (see e.g. Lacy et al. 2001; Ghisellini & Celotti 2001). If maximally spinning, its rotational energy is more than enough to account for the energy contained in the radio-lobes of radio-loud sources. There may be a problem, however, in the mechanisms proposed so far to extract this rotational energy. They must be very efficient. Indeed, jets can transport more power than that radiated by accretion disks: this is obviously true in GRBs, but it is also the case for lineless BL Lac objects and Galactic Superluminal sources during major radio flares. In fact, as already known at low accretion rates, the accretion disk luminosity could be lowered by the de-coupling of proton and electrons (Rees et al. 1982, Narayan, Garcia & McClintock 1997), while, at high accretion rates, the optical depth of the accretion disk is large enough to trap photons (Begelman 1979). Jets seem not to be bound by these limitations.

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